12, 1967
Reclamation Assoc.
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# HARVESTING THE NATIONAL FOREST WATER CROP

Seventy percent of the water that falls as precipitation on the continental United States is used in evapotranspiration from the nonirrigated lands. If only 1 percent of this evapotranspiration is converted to streamflow, the metropolitan water needs of the present day population of the United States would be met.

In the arid West the evapotranspiration component of water supply management is even more striking. For example, in the Colorado River basin less than 10 percent of the precipitation appears as runoff in the river.

This is the magnitude of evapotranspiration--the component of the hydrologic cycle, the subject of much research but largely overlooked in action programs of water supply that lends itself to improved harvesting methods. A harvesting program that can produce a larger crop of water to serve the needs of people, for agriculture, for industry, for recreation, and for domestic purposes.

My purpose today is to explain how the National Forest System of the Western United States can contribute more to these water supply needs.

In the 11 Western States, the National Forests occupy 21 percent of the area, receive 32 percent of the precipitation, and produce more than 20 percent of the total runoff. The average annual runoff from the National Forests is 14 inches, as compared with 3-1/3 inches from areas outside the forest boundaries.

Three and one-half percent of Colorado is in the alpine zone and produces 20 percent of the State's runoff.

These humid islands surrounded by semiarid-to-arid lowlands are in effect enormous water factories. Water factories provided by nature--but still awaiting the creative cooperation of the watershed scientist to set its productive capacity into motion.

The scientific basis for a water harvesting program. Building on the scientific observations of other countries, the Forest Service, in cooperation with the Weather Bureau, began its research program at Wagon Wheel Gap in 1909. Here it was conclusively proven that increasing runoff through management of vegetation was possible. Since then, Forest Service watershed research aimed at increasing water production from forested lands has continued and expanded to provide basic scientific know-how in each of the major hydrologic provinces of the United States. This research includes snow fencing in the alpine zone,

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Presented at 36th Annual Convention of National Reclamation Association, Honolulu, Hawaii - week of November 12, 1967, by Byron Beattie, Director, Division of Watershed Management, Forest Service, U.S.D.A.

brushland management in the areas below the commercial zone, treatment of riparian vegetation, and management of the commercial timber zone for a variety of water production purposes.

The magnitude of response to treatments ranges from an acre-foot of water for each mile of snow fence to an acre-inch of water on marginal areas in the chaparral zone.

I want to emphasize that these results represent potential rather than attainable results. Usually they reflect the results of a single purpose treatment technique rather than what can be obtained from an operational program of applied management which must be harmonized with other resource values--forage production--timber production--fish and game habitat--outdoor recreation--and scenic and esthetic values. Regardless of this restraint, a foundation of more than half a century of solid research results means that a program of scientific management to increase usable water supply is beyond the point of speculation--it is a program that can be put in motion and one that is presently underway at a modest level.

## THE BAROMETER WATERSHED

Just as a farming operation must be adapted to the particular crop being grown, and the crop adjusted to the terrain, the climate and the soils, so too, must a water harvesting program be adapted to an individual watershed. It is equally necessary to adapt individual research findings developed at various locations to a synthesized whole for operational application on managed watersheds.

To bridge the gap between research findings on small watersheds and operational water yield improvement programs on larger watersheds, the Forest Service is establishing a system of "barometer watersheds."

These watersheds range from 50,000 to 150,000 acres--the same size used in planning and applying the operational program of water yield improvement. A barometer watershed is being established in each broad climatic-physiographic region or hydrologic province. About 50 barometer watersheds are necessary to serve the 186,000,000 acre National Forest System. These watersheds are used to develop detailed methods, procedures, parameter values, and prediction equations for use throughout the hydrologic province they represent. Each watershed is analyzed hydrologically to provide a basis for evaluating the effects of normal management and use upon the soil and water resources and for preparing watershed prescriptions to protect and improve those resources. A hydrologic analysis of a

watershed is based upon an intensive inventory to determine its physical, geologic, soil, climatic, and vegetation characteristics. This information is then analyzed, parameter by parameter, for each climatic event for all the hydrologic processes of interception, evaporation, transpiration, surface runoff, infiltration, soil and rock storage, transmission, and discharge (yield). When the watershed is adequately characterized and the present values for each parameter determined, the contribution to water yield due to the alteration or modification of each parameter can be evaluated. Thus, the hydrologic analysis becomes the basis for predicting the effect of alternative programs of soil, vegetation, and land treatment measures--including structures--on the quantity, timing, and quality of water yields. It also provides the means for valid economic appraisal of each proposed program.

The barometer watersheds are instrumented to measure all important climatic factors influencing hydrologic behavior. These include, as a minimum, absorbed radiation, wind movement, temperature, dewpoint, and precipitation. One, or more, reliable stream-gaging and sediment sampling stations with permanent controls is installed. These are equipped with recording instruments. In addition to total streamflow from the watershed, the instruments make it possible to determine distribution of runoff throughout the year, including such important elements as low and high flows and the runoff response to individual climatic events. They also record important changes in water quality that may result from land management practices or are important to the suitability of water for intended downstream users.

The instrumentation of these watersheds makes it possible to measure all elements of water inflow and outflow with reasonable accuracy, except for that in the form of deep seepage from the watershed.

Supplemental measurements of soil erosion on watershed slopes and along stream channels provide a basis for determining sediment sources and for evaluating the effectiveness of various treatments in reducing soil losses.

Companion studies are also made to evaluate the effects of treatments and uses upon the other resources and values within the watershed--including effect on ecological communities, timber production, grazing values, fish and wildlife habitat, and recreation or scenic values.

The barometer watershed has many important purposes. It provides a means of translating research findings to applied management. Since the watershed scientist predicts the consequences of land management programs in advance of their occurrences, the measured output serves as a check on the accuracy of his prediction. Where there is significant difference between predicted and actual response, it is possible to determine which parameters were responsible and to adjust

their relative values in the computation of yield and to make adjustments in the management prescriptions so as to achieve maximum water yields in harmony with other resource values.

Barometer watersheds are extremely valuable in training and developing watershed managers. They offer exceptional opportunity for demonstrating the techniques and values of managing forested lands for their water values to policy makers, to water users, and to budgetary officials,the people largely responsible for shaping management programs. The system of barometer watersheds is not a research facility. It is an important management tool.

## THE WATER HARVESTING METHODS

A projection of research findings indicates that in the West 9 million acre-feet of increased water yield can be obtained from forest, brush, and alpine watershed treatments for an average annual cost of 13 million dollars. This additional water has an estimated primary delivered value, weighted according to agricultural, industrial, and domestic uses, of almost one-half billion dollars annually.

While there are many refinements of these watershed treatment measures, the basic treatments are as follows:

Snow fencing in the alpine zone or in other large openings in the heavy snowpack zone.

Rearrangement or reductions of the vegetation mass in the timber harvest zone, and

Conversion of deep-rooted stands of dense brush, non commercial timber or riparian vegetation to shallower rooted stands of grass.

Snow fencing in the Alpine Zone. The purpose of snow fencing is to induce snow to accumulate in deep drifts. This is accomplished by causing air turbulance on the leeward side of the fence, bringing the snow into a sheltered air pocket where it is deposited. This same snow, if not deposited, would continue airborne until evaporated or until intercepted by trees at lower elevation where a large part is evaporated without reaching the ground. We have found, both in research studies and in operational application, that a mile of fence will accumulate about 50 acre-feet of additional water.

In addition to the accumulation effect of snow fencing, the deep drifts are very effective in prolonging the snow melt period--thus yielding water later in the season during the period of greatest need. Supplemental practices, available but not yet used in our management program, include the use of evaporation suppressants to further reduce peak flows and prolong the period of runoff and the use of carbon black to speedup or to complete snowpack melt where the carryover storage is not desired.

Our initial cost of water production through snow fencing is running about $23 per acre-foot over the useful life of the facility. Cost of fencing has declined from $7 per foot to $5 per foot in the 2 years of experience. We expect, as we gain more experience, to reduce this to the point where we can produce additional water in the alpine area through snow fencing and other supplemental treatments to a cost of $8 per acre-foot.

Vegetation Management in the Commercial Timber Zone. In the commercial timber zone managed water production results from two effects. The first is the reduction of evapotranspiration with a corresponding increase in water yield. The second is induced snow accumulation by changing the pattern of forest cover. The principle is the same as in snow fencing, i.e., a modification of wind movement to create air turbulance and dead air pockets.

The reduction of evapotranspiration in the commercial timber zone comes as a corollary consequence of the timber harvesting program. The yield increase is in proportion to the amount of vegetation removed. However, unless scientific consideration of the water yield effects is blended into the timber harvest program, we have no assurance that we are receiving the full benefits in terms of water yield.

Yet it is in the snowpack part of the commercial timber zone that the best opportunities for managed harvest of the National Forest water crop are found. Precipitation in this zone ranges from 20 to 100 inches annually, and almost half of this appears as streamflow. It is the largest water production area of the western National Forests, and this area is being treated on a continuing basis in furtherance of the timber production program. In fact, more than half a million acres are being treated annually in National Forest watersheds tributary to the water-short areas of the Western United States.

Research conducted under a wide variety of circumstances shows that yield increases will vary greatly between watersheds. In the white pine forests of northern Idaho water yield increased by 4.2 inches in changing from a closed canopy to a completely open canopy comparable to our usual silvicultural system of clear-cutting. This represents an average water gain of 32 percent from the treated areas. In the

true fir and mixed conifer high elevation forests of the Sierra Nevada in California an 8.6 inches increase (40 percent) resulted from a system of strip-cutting. Block cutting in this same type showed a 6.3 inch or 30 percent gain in water yield, while single tree selection resulted in an increase of 3.4 inches, or 16 percent.

On the west slopes of the Cascade range in Oregon clear cutting 30 percent of the watershed increased late summer flows by 12 to 28 percent. In a similar watershed removal of trees from 80 percent of the watershed increased low flows by 85 percent.

In the Big Horn Mountains of Wyoming clearcutting mature lodgepole in blocks resulted in a peak snowpack 40 percent greater than in the uncut forests.

In the 1909 Wagon Wheel Gap study in Colorado, where annual precipitation averages only 21 inches, runoff was increased by 16 percent as a result of vegetation management.

To capitalize on this storehouse of research findings and the extensive treatment program associated with the National Forest timber harvest program will require additional expense if an improved water yield is to be assured. First is the cost of hydrologic analyses and design of the treatment prescription. Second is the increased cost of the timber harvesting operation if something other than the least cost method needed to accomplish the timber harvest and post harvest treatment programs is used. These additional costs are estimated to range from $1 to $8 per acre-foot of additional water produced. They are properly chargeable to water production.

Vegetation Management in Noncommercial Forests. Conversion of deep-rooted stands of brush, noncommercial timber and riparian vegetation is the third major treatment program that the Forest Service uses to increase water production.

Most of the noncommercial timber lands are located in a rather broad belt between the alpine lands and the commercial timber zone. These are areas of high precipitation and high water yield. Aspen is the common tree species associated with this zone. Research conducted in Utah showed that by converting the aspen cover to a herbaceous cover an additional 4 inches of water was made available for streamflow. Comparable studies in western Colorado showed that on soils deeper than 4 feet an increased yield could be expected by converting from aspen to grass. This study showed that aspen withdrew an additional 9 inches of water through evapotranspiration than did grass from soils between depths of 4 and 8 feet.

Another large body of forest land that lends itself to improved water harvesting techniques is the millions of acres of brushland below the commercial timberlands. The primary value of this brush cover is to stabilize the soil and to reduce the threat of flood runoff during long duration storms. In much of this vegetation zone, it is important to maintain this brush cover. There are, however, numerous places where type conversion to increase water yield can be done without accelerating erosion or flood runoff. Generally, these are in areas where annual precipitation exceeds 18 inches and where the soils are deeper than would be occupied by grass. In these areas the amount of the increase which can be expected is roughly proportional to the depth of the soil and fractured rock zone on the treated areas.

One of the more spectacular research findings in this vegetative type was at the 3-Bar experimental watershed in Arizona. Here a 77-acre watershed--after the dense brush was replaced with grass--produced 8 inches of water, compared with 2 inches prior to treatment under similar amounts of precipitation. Research conducted in southern California on type conversion from brush to grass showed a potential groundwater yield increase of 6.4 inches.

This is comparable to the yield increase we are obtaining from the more favorable sites in our barometer and managed watersheds.

This range of yield increase potential is further confirmed by a recently completed hydrologic analysis of the 350,000-acre Mazatzal province in the Tonto National Forest in Arizona. Average annual precipitation ranges from 16 to 25 inches within the area. This analysis--based on a reconnaissance level survey--identified 99,000 acres of treatable land. Increases from the brush areas would range from 1 inch on the poorer sites to 5 inches on the best sites. If intensively managed for water production, an additional 43,000 acre-feet would be produced.

This includes about 11,000 acre-feet of water from about 6,000 acres of treatable riparian vegetation or an increase of about 18 inches per acre treated.

Based on our experience to date in the Santa Ynez and Salt-Verde drainages where we have a fairly large scale action program of type conversion underway, the cost of water production in the chaparral zone will range from $10-$15 per acre-foot on the more productive sites.

It can be seen from this that management of riparian vegetation is a prime source of increased water supply. Treatment not only results in the largest evapotranspiration reduction, but because these areas are immediately adjacent to the streams, transmission losses are low.

The effectiveness of riparian vegetation management is illustrated by two research projects conducted in strongly contrasting hydrologic situations.

The first was removal of 38 acres of riparian and woodland vegetation in and along a mountain stream channel within the Angeles National Forest in southern California. This resulted in an additional 30 acre-feet of streamflow following a year of above average rainfall, and 22 acre-feet following a year of below average rainfall. Gains in streamflow were highest during the dry season when water is most needed and lowest during the rainy season.

The second was in the commercial timber zone of the Sierra Ancha Experimental Forest in Arizona. Here 80 acres of moist site vegetation, mostly white fir and Douglas-fir, were removed from a strip of land on either side of Workman Creek. The treated area, about 385 feet wide and 9,000 feet long, was about one-third of the total watershed area. The increased yield of water amounted to 5.4 inches from the treated area, or 55 percent over pretreatment conditions for the watershed as a whole.

## THE WATER HARVESTING PROGRAM

As we see it, an action program to harvest the National Forest water crop in a particular watershed will encompass one or more of the measures just described. The starting point of such an action program is the hydrologic survey and analysis leading to a prescription or treatment program, compatible with the development and use of other resource values in the particular watershed.

Survey and Analysis. This requires a careful and detailed survey and evaluation of each of the factors that influence the hydrologic behavior of the watershed.

This information is interpreted in such a way as to determine the effect of each factor--individually and collectively--on the disposition of precipitation through interception, evaporation, transpiration, infiltration, and deep percolation.

In this we use an energy balance accounting method to determine evapotranspiration potential under a range of land treatment programs. Next we determine that part of available water that will go into subsurface runoff through infiltration and deep percolation. Finally, to complete the water budget analysis, we determine the amount which will leave the watershed in the form of streamflow. This discharge from the watershed is presented in the form of stream hydrograph, comparing the pretreatment seasonal and annual yield of water with that which will result from the prescribed treatment program.

Multiple Use Coordination. The next step in developing the water production prescription is coordination with other resource programs. This is an essential step in obtaining an optimum product mix from a multiple use property. In this part of the job, other resource scientists review the alternative treatment prescriptions to determine their effect on such things as timber production, forage production, wildlife habitat, the recreation development program, and of increasing importance, their effect on scenic attributes of the watershed. This results in selection of that treatment plan that best fits the multiple use objectives for the watershed.

The final product is a detailed description of the selected treatment program, the cost of treatments chargeable to water production, and the annual increase in water yields that can be expected for years of high-low and average precipitation.

The Action Program. At present the water harvesting program is underway in only four watersheds--one in the alpine zone and three in the brushland zone.

The alpine zone project is in the Lake Creek watershed in Colorado. This 42,000 acre watershed on the San Isabel National Forest flows directly into the Twin Lakes reservoir--a part of the Fryingpan-Arkansas project. We have installed 2 miles of fence to date. Our plan of operation includes avalanching of snow accumulations. So far, however, we have been largely unsuccessful. We have tried the practice of using 75 mm. recoilless rifles that has been very successful in ski areas. We also found that sonic boom, at least under the prevailing conditions at the time of the test, was unsuccessful. In time we will find a practical avalanching technique, and when we do the effectiveness of snow fencing can be increased from 3 to 5 times.

One of the three brushland projects is in the Big Creek watershed on the Sierra National Forest in central California. Within this watershed--a tributary to the Kings River and the Corps of Engineers' Pine Flat reservoir--there are almost 11,000 acres of treatable brushland and 12,000 acres of treatable timberland. To date, 1,500 acres of dense brush--on deep soils--have been converted to a permanent grass cover with a computed 200 acre-foot increase in water production.

The second brushland water harvesting project, also in California, is the Santa Ynez watershed on the Los Padres National Forest. This 138,000 acre watershed is the primary source of domestic water for the cities of Santa Barbara and Montecito and, through the Bureau of Reclamation, Cachuma reservoir provides irrigation water for some of the high value agricultural lands in the Santa Ynez valley. There are

57,600 acres of treatable brushland and 5,400 acres of treatable phreatophyte and other riparian vegegation. When completed this treatment program will produce an additional 18,240 acre-feet of water in years of average precipitation, much of which will be delivered during the summer and early fall low flow period.

To date, we have converted 3,300 acres of dense chaparral to a perennial grass cover with computed water production increases ranging from 1.9 inches to 9.5 inches, depending upon location and variation in climatic conditions. This initial treatment program is producing an additional 1,500 acre-feet of water per year above natural yields.

The first of the brushland projects to be undertaken by the Forest Service--and the largest one--is on the Tonto National Forest in Arizona. This project is an outgrowth of the Beaver Creek project in Arizona--a joint effort of National Forest management and Forest Service research, initiated in 1957. The primary purpose of the Beaver Creek project was to determine the effect of various land treatments on water yield when applied at an operational level.

Encouraged by the early results in Beaver Creek, in 1962 it was decided to broaden the program of operational management to increase water yield to other typical watersheds. The strong interest in the program on the part of the Salt River Valley Water Users Association and the Arizona Water Resources Committee, combined with the obvious need for additional water, dictated that initial plans include a water production program for the 4½ million acres of National Forest lands tributary to the Salt and Verde Rivers. In 1964 the Salt River Valley Water Users Association decided that an accelerated program was desirable. To make this possible, a cooperative agreement was executed to enable them to participate financially in the treatment program on National Forest lands.

So far the land treatment program has been confined to the lower elevation brushland areas; 12,350 acres have been treated to date, with a computed yield increase of 5,500 acre-feet. In addition to the land treatment measures, considerable survey and analysis effort has been expended in identifying and classifying areas suitable for treatment. This has been at a reconnaissance level. The field survey work is now completed and the analysis is scheduled for completion within the next year. This will permit us to present to our cooperators a complete package of water production potential as a basis for their overall planning of water use and development activities in the Salt River project area.

## THE LOOK AHEAD

Building on the experience gained from the Salt-Verde project and in response to the Bureau of Reclamation's Pacific Southwest Water Plan, the Forest Service has underway a reconnaissance level survey of the 40 million acres of National Forest lands tributary to the Colorado River--the Central Valley of California, and the coastal area of southern California.

The Pacific Southwest Survey. This survey will give us for the first time some idea of what the opportunities to increase water yield on a large scale might be. We expect to complete the survey in late 1968. It is designed to:

1. Identify and map areas suitable for water production management and to develop an estimate of the potential yield increase.

2. Identify and map areas of accelerated erosion and the need or potential for reduction in sediment yield.

3. Provide a basis for establishing a priority of treatment programs.

The field survey is being made by teams composed of a soil scientist, a watershed scientist, and an ecologist. Twelve barometer watersheds, with a gross acreage of 906,000 acres--about 2 percent of the total survey area--will provide much of the foundation knowledge for application to the hydrologic province they represent.

In these watersheds, we have the benefit of an intensive survey of each hydrologic feature--climate, vegetation, soil, and runoff--and have developed a prediction of potential hydrologic response to a designed treatment program.

The reconnaissance level survey will consider these same hydrologic features individually and collectively.

The survey will use existing data to develop temperature, wind, net radiation, precipitation, and runoff characteristics within each hydrologic province. This, in combination with a map of major cover types, will be used to compute evapotranspiration rates. Soil and geologic features will use existing information supplemented by spot sampling to arrive at infiltration, deep percolation, and sedimentation rates.

Then, by comparative analysis, the predicted hydrologic response within the barometer watersheds will be extended to the total survey area to arrive at a first approximation of water yield increase and sediment reduction potentials.

Based on the detailed hydrologic analysis of the 12 barometer watersheds associated with the survey area, it appears that through intensive management an additional 4 million acre-feet of water can be harvested from that part of the 40 million acres outside the Wilderness System. This first approximation will be refined through comprehensive hydrologic surveys and prescriptions of individual watersheds. This phase of the job will be carried forward on priority areas identified in the reconnaissance survey.

Selection of Treatment Areas. Under the current and foreseeable financial restraints, selection of watersheds for priority consideration becomes a vital step. In general terms, we can and do give priority to the arid West. Also in general terms, we can, as we have in the case of the Salt-Verde project, give high priority to areas of current over-utilization of available supplies--where, unless additional water is made available--a major adjustment or a decline in the economy is the inevitable consequence. Such considerations as these may call for priority attention to watersheds where the acre-foot yield per dollar of investment is not the most favorable.

Another important factor in determining priorities is the presence of an installed delivery system--the structural works of improvement--the processing plant which converts raw water to a useful commodity. These are the hydroelectric plants, the reclamation projects, and the State and locally installed municipal supply or irrigation projects associated with National Forest lands.

The fact that these structural works were installed means that water supply needs have been established, justified and amortized on the basis of available supplies. Under these circumstances the incremental value of additional water to the installed structural delivery system reaches unusually high levels.

Finally, however, priorities both within the program and between this program and other resource development programs will be established largely through the democratic process.

## IN SUMMARY

1. We have a strong body of research knowledge on which to base an action program.

2. We have a system of barometer watersheds to translate research findings into operational management programs to measure water yield.

3. The National Forests occupy the bulk of the available water production areas of the Western United States.

4. We have a massive treatment program underway in the commercial timber zone, which can be adapted to attain improved water yields.

5. We have underway a small action program in the alpine and brushland areas, which is demonstrating that significant water yield increase can be obtained in harmony with the protection and utilization of other resource values.

6. A year from now we will have identified and quantified the potential for increased water production on all National Forest lands tributary to the water deficient metropolitan, agricultural, and industrial Pacific Southwest region of the United States.

7. The program can and will be accelerated when public interest in this overlooked field of water resource development expresses itself in a manner that provides the financial resources needed to do the job.

It is a Forest Service responsibility to develop the cold hard facts of what can be done through a scientifically designed program to harvest the National Forest water crop--and this we are doing. But, without the vigorous, knowledgeable and broad-based public support of water user groups, such as can be provided by the National Reclamation Association, this water harvesting program will remain in the category of foregone opportunities.

The program must be understood and people must be convinced--as we are--that water harvesting from National Forest lands is an essential element of the total program for harvesting and harnessing the Nation's water resources.

I hope I have contributed to your understanding.